

Energy expenditure does not predict weight change in either Nigerian or African American women^{1–3}

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ABSTRACT

Background: The relation between variation in interindividual levels of energy expenditure and weight gain remains controversial.

Objective: To determine whether or not components of the energy budget predict weight change, we conducted an international comparative study in 2 cohorts of women from sociocultural environments that give rise to the extremes of obesity prevalence.

Design: This was a prospective study with energy expenditure measured at baseline and weight measured annually for 3 y. Participants included 149 women from rural Nigeria and 172 African American women. The energy budget was determined by using respiratory gas exchange and doubly labeled water. Main outcomes included total, resting, and activity energy expenditure and physical activity level (ie, total energy expenditure/resting energy expenditure); baseline anthropometric measures; and annual weight change.

Results: Mean body mass index (in kg/m²) was 23 among the Nigerians and 31 among the African Americans; the prevalences of obesity were 7% and 50%, respectively. After adjustment for body size, no differences in mean activity energy expenditure or physical activity level were observed between the 2 cohorts. In addition, in a mixed-effects, random-coefficient model, interindividual variation in activity energy expenditure at baseline was unrelated to the subsequent pattern of weight change.

Conclusions: These data suggest that interindividual levels of energy expended during activity do not have a large influence on age-related trends in adiposity. In addition, contrary to expectations, these data suggest that mean activity energy expenditure does not vary substantially between contemporary social groups with low and high prevalences of obesity. *Am J Clin Nutr* 2009;89:169–76.

INTRODUCTION

In weight-stable societies a combination of social cues and biological stimuli, presumably working through hormones that control satiety, are used to maintain near-perfect energy balance over many years. Over the past 50 y, however, an increasing number of industrialized societies have experienced substantial weight gain with age (1, 2). Likewise, as populations in developing countries migrate to urban centers and gain access to a mechanized lifestyle and inexpensive energy sources, the prevalence of obesity has begun to increase rapidly (1, 2). Why the normal regulatory process controlling fat stores fails under modern living conditions is not well understood. Age-related weight gain can only result from a chronic excess of energy intake over expendi-

ture; however, in the absence of quantitative measures of the relative impact of either component, this observation is uninformative about the underlying process. Unraveling the etiologic mechanism that leads to obesity will therefore require robust estimates of the relative contribution of intake, expenditure, and the regulation of energy balance.

In the United States, minority women have experienced a high burden of obesity in recent decades. Although the prevalence appears to have leveled off since 2000, 45% of African American women currently have a body mass index (BMI; in kg/m²) >30 (3). In contrast, <7% of adult women in rural West Africa are obese (4, 5). The environments in which these women live differ dramatically on many dimensions, including both diet and physical activity patterns, and the contrast between US and West African women must include those factors that have driven obesity upward.

It is commonly accepted that individuals living in developing countries expend relatively high levels of energy in physical activity, primarily through the requirements of manual occupations and other activities of daily living. It is further assumed that this increased expenditure is responsible, at least in part, for the lower rates of obesity in developing countries (2). In support of this view, a cross-sectional study among the Pima Indians suggested a much lower expenditure in physical activity among those residing on the Gila River reservation in Arizona compared than in those in the mountains of northern Mexico (6). On the other hand, we recently reported no mean difference in

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activity energy expenditure (AEE) among women in Nigeria and the United States (7).

Group-level comparisons can be complimented with an examination of AEE as a predictor of change in weight over time in individuals. Objective measures of AEE have been used in a cohort study of weight change in 2 populations (8, 9). A longitudinal study among the Arizona Pima Indians found that AEE did not predict weight gain, although low resting energy expenditure (REE) was associated with a risk of increasing adiposity (8). In contrast, in a study of 739 middle-aged adults in the United Kingdom, baseline AEE, measured with heart rate monitoring, was found to be inversely associated with changes in fat mass (FM), but not with body weight, in the younger participants and was positively associated with weight gain in the older half of the sample (9). We extend the knowledge base on this important question in this report with data from the longitudinal phase of our study of AEE in women in Nigeria and the United States.

SUBJECTS AND METHODS

Participants

The Department of Preventive Medicine and Epidemiology at Loyola University School of Medicine and the University of Ibadan (Nigeria) have collaborated on cross-cultural, population-based research on blood pressure and related traits since the early 1990s (10, 11). The participants enrolled in the present study were recruited from the existing database of the population surveys in rural Nigeria and suburban Chicago. The protocol was approved by the Institutional Review Board of Loyola University School of Medicine and the Ethics Committee of University College Hospital, University of Ibadan. Written informed consent was obtained from all participants; all relevant documents, including the informed consent form, were translated into Yoruba for the Nigerian site.

The study sites included 2 rural villages in southwest Nigeria, Igbo-Ora and Idere, and the predominantly African American communities of Maywood, a suburb adjacent to Chicago, and the neighborhood of Austin, which is located just within the Western boundary of Chicago. The primary occupation of the women in Nigeria was market trading (43%); a substantial proportion of the women also engaged in subsistence farming (21%). In contrast, the women at the US site were employed in a wide variety of occupations, the most common being certified nurse assistant (8%), followed by customer service representative (6%); 51% of the US cohort was unemployed at the time of the baseline examination.

Women were asked to participate if they were between the ages of 18 and 59 y, in general good health, and not pregnant or lactating at the time of the baseline examination. Other exclusion criteria included having plans to travel outside the study area during the doubly labeled water (DLW) measurement period, actively trying to lose weight, thyroid dysfunction, or orthopedic or other conditions that restricted movement. A standardized protocol that included measurement of total energy expenditure (TEE) with the DLW method, REE by respiratory gas exchange, and body composition by isotope dilution was used for both the Nigerian and US cohorts. Additionally, anthropometric measurements and medical history were collected.

The research teams used clinic space convenient to the participant populations in both Nigeria (in Igbo-Ora) and the United States (in Maywood). Participants arrived at the respective clinics at ≈ 0700 after an 8- to 10-h overnight fast. The baseline examination required a minimum of 5 h to complete, after which the participants were provided with a light meal and instructions for completing the DLW protocol. One woman from each site died within 12 mo of enrollment (the Nigerian woman from cancer and the US woman from cardiovascular disease); these women were excluded from the analyses.

Total energy expenditure

Free-living TEE (MJ/d) was measured over a period of 10–14 d with the DLW technique, as previously described in detail (12, 13). A 10-d measurement period was used in Nigeria because of the potentially more rapid water turnover in tropical regions ($k_D = 0.1237$), whereas a 14-d period was used in the United States ($k_D = 0.0786$). All EE data are expressed per day, taking the site-specific measurement period length into account. Briefly, deuterium and ^{18}O elimination rates were calculated by using the 2-point method with the use of isotopic enrichment relative to baseline and the time difference between the third postdose and final urine samples (14). Participants provided a baseline urine sample and drank a preweighed dose of DLW. The dose included 0.14 g deuterium and 0.20 g ^{18}O per kilogram of total body water. Urine samples were then collected 2, 4, and 5 h after isotope administration. In Nigeria, a midpoint spot urine sample was collected on day 5, and an endpoint sample was collected on day 10 after the isotope administration. In the United States, 2 urine samples were collected on day 14—at the first void of the morning and again ≥ 2 h later in the clinic. Regardless of site, participants returned to the respective clinics on day 10 or 14, where they provided the final urine sample and their weights were recorded. All urine samples were analyzed for isotopic abundance at the Stable Isotope Core Laboratory of the University of Wisconsin, Madison. Site-specific food quotients (0.90 for Nigeria and 0.85 for the US) were used in the calculation of TEE. These food quotients were based on unpublished 24-h dietary recall data indicating, on average, a high-carbohydrate diet in Nigeria, comparable with that previously reported for West Africa (15, 16) and with a typical Western diet in the United States. TEE was expressed as MJ/d.

Because of the potential for season-specific variation in TEE (17) and to assess reproducibility, we repeated the DLW procedure in 9 Nigerian women. The initial measurement was made during the dry season (ie, January to March 2000), and the second measurement 18 mo later during the rainy season (August 2002).

Resting energy expenditure

After the collection of a baseline urine sample and the administration of the isotopes, REE and resting respiratory quotient (RQ) were by measured indirect calorimetry with a single instrument (DeltaTrac II; Viasys Medical Systems, Palm Springs, CA) at both sites. Fasting 40-min measurements were completed after the participant had lain at rest for 20–30 min. The DeltaTrac II operates as an open-circuit canopy system with a paramagnetic oxygen sensor, infrared carbon dioxide analyzer, and onboard computer. Briefly, rates of oxygen consumption and carbon dioxide

production were calculated and used to calculate REE by using the modified equation of Weir (18). The last 20–30 min of data were used to determine the average REE, which was expressed as MJ/d. As previously reported (19), before each measurement, the indirect calorimeter was calibrated by using a gas of known concentration. Flow rate and carbon dioxide recovery were assessed monthly by using alcohol burn tests; these measures indicated that the unit operated within 2% of predicted values at all times.

Activity energy expenditure

Activity EE (MJ/d) was calculated as follows: $AEE = (0.9 \times TEE - REE)$, where the term $(0.9 \times TEE)$ represents the estimated 10% of TEE expended as the thermic effect of food (20). Physical activity level (PAL) was calculated as the ratio of TEE to REE.

Anthropometric measurement and body composition

Height was measured, while the subjects were shoeless, to the nearest 0.1 cm with a wall-mounted stadiometer (Seca Corp, San Jose, CA). Weight was measured while the subjects were shoeless and wearing light clothing to the nearest 0.1 kg with a calibrated balance (Health-o-meter, Bridgeview, IL). Height and weight measurements were used to calculate BMI as $\text{weight (in kg)} / \text{height}^2 \text{ (in m)}$. Body composition at the baseline examination was measured by using the stable-isotope dilution method, as previously described by Schoeller et al (21). Total body water was calculated from both deuterium and ^{18}O dilution spaces, and the 2 values were averaged. Fat-free mass (FFM) was calculated from total body water by using a constant hydration factor (0.73) (22), and FM was calculated as the difference between body weight and FFM.

Medical history and annual examinations

Participants were asked about their medical history (including the presence of known chronic diseases), smoking and drinking habits, usual occupation, time since last illness requiring time off from work, and number of pregnancies. The women were asked to return every 12 (± 2) mo for the 3 y after the baseline examination for measurement of body weight and questions about pregnancy and their general health since the previous examination. To ensure quality control between the study sites, clinic field staff were trained and certified by the project coordinator, and all procedures used standardized forms, training, and certification, survey, and sampling methods.

Statistical analysis

EE data are presented both in absolute measures and after correction for body size and composition. TEE, REE, and AEE were adjusted for FFM and FM by using a regression method, as described previously (23). Means and SDs were calculated for all variables. Student's *t* test was used to assess differences between the 2 sites. The potential impact of loss to follow-up for a subset of the cohort was examined by various sensitivity analyses.

The association between adjusted TEE, as well as REE and AEE, and weight change was investigated by using both a de-

scriptive and a model-based approach. For the descriptive approach, the rate of weight change per year was estimated by regressing weight (in kg) on time for each individual with ≥ 3 weight determinations. Although 2 weight measurements provide enough information to estimate the slope, with ≥ 3 measurements it is possible to also estimate the SE of the slopes. The resulting slopes were then plotted against adjusted TEE (REE and AEE), and the association was tested by using simple linear regression.

This descriptive approach was naturally extended by a multilevel analysis that involved mixed-effects, random-coefficient models. Briefly, weight (in kg) at each examination is regressed on time (in y) from the entry date (Level 1). The next stage (Level 2) models the potential dependence of the individual baseline weight (intercept from LEVEL 1) and rate of weight change (slope from Level 1) as a function of other covariates. Precisely, the multilevel model for adjusted AEE was as follows:

$$\text{Level 1: Weight}_{ij} = \beta_{0i} + \beta_{1i}T_{ij} + \varepsilon_{ij} \quad (1)$$

$$\text{Level 2: } \beta_{0i} = \alpha + \alpha_1 \text{Base weight}_i + \alpha_2 \text{Age}_i + \alpha_3 \text{AEE}_i + \alpha_4 \text{Site}_i + \xi_{0i} \quad (2)$$

$$\beta_{1i} = \gamma_0 + \gamma_1 \text{AEE}_i + \gamma_2 \text{Site}_i + \xi_{1i} \quad (3)$$

where $i = 1, 2, \dots, N$, and $j = 1, 2, \dots, n_i$.

Thus, the effect of AEE on weight change per year is measured by the interaction coefficient γ_1 , and the average effect of AEE on weight is estimated by α_3 . Models for REE and TEE were also fitted. The advantages of this multilevel approach include the fact that all available information, even incomplete data, could be used for analysis, and both within- and between-person variability in weight change could be taken into account, as could potential confounders, such as age and baseline weight. In addition, we applied a random-effects pattern-mixture model to examine the influence of missing data patterns on weight change estimates (24). All analyses were carried out by using the statistical package STATA, version 10.0 (Stata Corp, College Station, TX).

RESULTS

One hundred forty-nine women were enrolled in Nigeria and 172 in the United States. Subject characteristics at baseline are presented in **Table 1**. The Nigerian women weighed substantially less than their US counterparts and had lower BMI, FFM, and FM (all $P < 0.001$). Seven percent of the Nigerian and 50% of the US women were obese, ie, $\text{BMI} \geq 30$. Although much leaner on average than the US cohort, the Nigerian women were not suffering from calorie insufficiency because mean body fat was $28.9 \pm 7.6\%$ (range: 12.3–46.0%). Absolute body weight remained significantly different between the cohorts during the 3 y of follow-up. The annual change in body weight was, however, comparable in the 2 cohorts (means of 0.61 and 0.52 kg/y in Nigerian and US women, respectively).

Ninety-five percent of the Nigerian ($n = 143$) and 75% of the US women ($n = 130$) completed a scheduled follow-up examination during which weight was measured. Sixty-six percent of the Nigerian and 49% of the US participants completed all 3 follow-up examinations. Among completers and noncompleters,

TABLE 1
Participant characteristics by site¹

	Nigeria	United States	P ²
Age (y)	31.9 ± 11.6 ³	34.6 ± 10.6	<0.05
BMI (kg/m ²)	23.1 ± 5.0	31.0 ± 7.7	<0.01
Fat-free mass (kg)	40.38 ± 5.34	48.88 ± 8.48	<0.01
Fat mass (kg)	17.90 ± 8.81	35.20 ± 15.29	<0.01
Total EE (MJ/d)	9.49 ± 1.69	10.16 ± 1.81	<0.01
Resting EE (MJ/d)	5.39 ± 0.67	5.82 ± 0.87	<0.01
Activity EE (MJ/d)	3.15 ± 1.31	3.32 ± 1.14	0.14
Adjusted total EE (MJ/d) ⁴	9.90 ± 1.41	9.37 ± 1.18	<0.01
Adjusted resting EE (MJ/d) ⁴	5.74 ± 0.43	5.47 ± 0.52	<0.01
Adjusted activity EE (MJ/d) ⁴	3.37 ± 1.30	3.17 ± 1.06	0.28
Physical activity level ⁵	1.77 ± 0.27	1.75 ± 0.20	0.49
Weight change (kg/y) ⁶	0.61 ± 1.6	0.52 ± 2.7	0.75

¹ Total *n* = 321 (149 Nigerian and 172 US women). EE, energy expenditure.

² Comparison of mean values between the 2 cohorts (Student's *t* test).

³ Mean ± SD (all such values).

⁴ Corrected for fat-free mass and fat mass by using regression-based adjustment.

⁵ Physical activity level = total EE/resting EE.

⁶ Estimates of weight change obtained with a descriptive approach, ie, slope of weight over time; only individuals with ≥3 weight determinations were used for the slope estimation (*n* = 107 Nigerian and 127 US women).

only baseline age among the Nigerians was significantly different. As noted below, sensitivity analyses indicated that differential loss to follow-up was unlikely to have influenced the results.

To correct for the significant differences in body size and composition, all EE data were adjusted for FFM and FM by using a regression-based adjustment (age was not a significant determinant of any EE variable and was omitted from all adjustments). Unadjusted TEE and REE were both lower in the Nigerian cohort (both *P* < 0.05), although adjusted TEE and REE were higher (*P* < 0.05). Potential explanations for the difference in adjusted REE between the 2 cohorts are described in detail elsewhere (7). In contrast with TEE and REE, neither adjusted AEE nor PAL differed between groups. For descriptive purposes the participants were further classified per the categories for PAL as defined by the Institute of Medicine: sedentary (PAL < 1.4), low active (PAL ≥ 1.4 to <1.6), active (PAL ≥ 1.6 to <1.9), or very active (PAL ≥ 1.9) (25). The distributions were essentially the same in both groups, with ≈50% of participants being classified as active and another 23% as very active (Figure 1).

The correlation between the replicate TEE measurements in the subset of participants in the study of seasonal variation was 0.80 (Table 2). The mean CV of within-person variation in TEE was 3.9% and in AEE was 10.7%, which suggested that that EE measurements by DLW were reproducible and the season of measurement did not likely impact EE levels of the Nigerian cohort. In neither cohort was season of measurement associated with TEE or AEE levels; we therefore did not further correct for the time of year when the data were collected in either cohort. For the initial analyses, participants were clustered into 3 age groups, ie, >25, 25–44, and ≥45 y, to investigate whether age was an independent predictor of weight change. No effect was found; therefore, all age groups within sites were combined for further analyses and age was included as a continuous variable

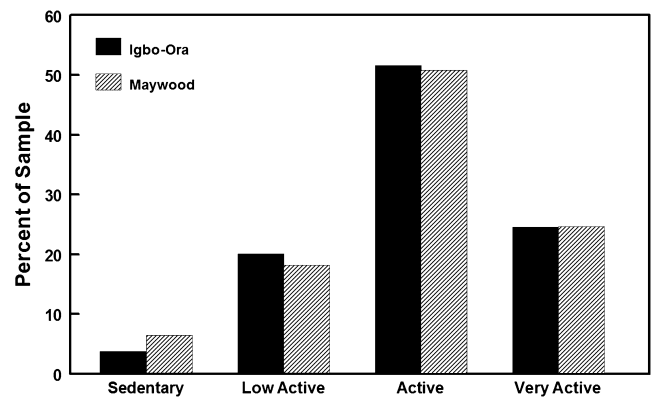


FIGURE 1. Distribution of physical activity levels (total energy expenditure/resting energy expenditure) among 149 Nigerian (black bars) and 172 African American (gray bars) women. Sedentary, <1.40; low active, ≥1.40 to <1.60; active, ≥1.60 to <1.90; very active, ≥1.90.

in all analyses. One Nigerian participant was omitted from the regression-based analyses because the baseline exam date was missing, which yielded a total sample size of 320 for all weight change analyses.

The descriptive approach for assessing the association between weight change and EE variables determination of the slope of weight change over time for each participant. There was substantial variability in the degree of weight change in both groups, including both positive and negative changes. Even though the mean change in weight did not differ between individuals in the 2 study samples, there were much wider absolute swings in weight in the United States (ratio of the variances for weight change = 0.6, Nigeria compared with the United States).

The test of the primary hypothesis is presented graphically in Figure 2. As is apparent, there were no significant associations between weight change and AEE at baseline, adjusted for FFM and FM, in either the Nigerian or US cohort. Similarly, there also was no association between weight change and baseline-adjusted TEE or REE in either cohort. We additionally analyzed the association between weight change and EE using both maximum weight gain (ie, the biggest gain in weight for an individual) and the maximum absolute change in weight per participant. In neither of these additional analyses were any associations observed for AEE, TEE, or REE.

TABLE 2
Replicate total energy expenditure measurements in Nigerian women

Subject	Measurement 1 (March/April 2000)	Measurement 2 (October 2001)	Intraindividual CV
	MJ/d	MJ/d	%
1	9.37	8.55	6.5
2	8.79	9.28	3.8
3	10.13	10.08	0.3
4	11.04	10.59	3.0
5	7.46	7.54	0.8
6	9.92	8.85	8.0
7	10.57	9.98	4.0
8	9.67	10.86	8.2
9	8.60	8.50	0.8
Mean	9.50	9.36	3.9

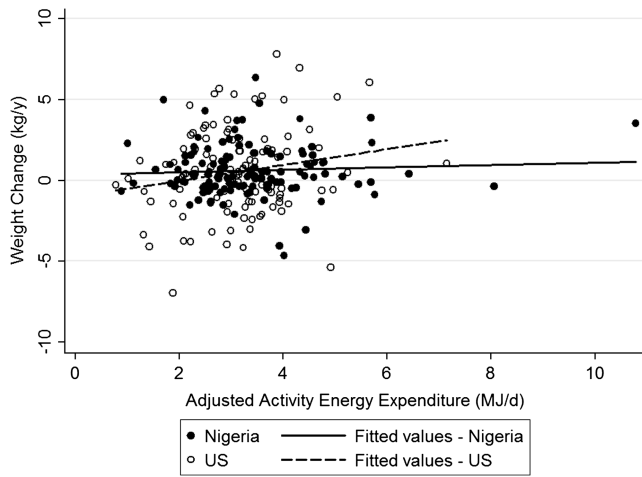


FIGURE 2. Scatter plot of weight change versus activity energy expenditure, adjusted for body composition, among 107 Nigerian and 127 African American women. Women with ≥ 3 weight determinations were included in this analysis.

The mixed-effects random-coefficient models were used to extend the analysis of the EE-weight change association and allow the use of all data for all participants while accounting for variability and potential confounders. In the reduced model, weight change was predicted only by time from baseline, after control for baseline weight; age was not significant (**Table 3**). On average, the participants gained 0.55 kg/y, both cohorts combined. The degree to which the prediction of weight change could be improved by the addition of measures of EE was then determined. In **Table 4**, we present the results for the mixed-effects, random-coefficient model for adjusted AEE. In model 1, only time was a significant predictor of weight change; addition of interaction terms for time-by-AEE and time-by-site yielded only baseline weight as predictive of weight change. The coefficient for time in model 1, 0.55 kg/y, was the same as that achieved with the reduced model, which indicated that adjusted AEE added no information to the prediction of weight change in these cohorts. Results from the mixed-effects, random-coefficient models for adjusted TEE and REE were consistent with the reduced model (data not shown). As presented in **Table 5**, a non-significant linear increase in both adjusted AEE and unadjusted PAL was observed, moving from the lowest tertile of weight change to the highest, which further confirmed that baseline EE was unassociated with risk of weight gain.

We explored the potential impact of bias resulting from incomplete follow-up at 2 levels. There was no meaningful asso-

TABLE 3
Reduced regression model predicting weight change over time¹

	Coefficient ²	95% CI	P
Baseline weight (kg)	0.991	0.979, 1.002	<0.001
Age (y)	-0.005	-0.027, 0.017	0.717
Time (y)	0.546	0.261, 0.830	<0.001

¹ $n = 148$ Nigerian and 172 US women with a total of 987 weight determinations. Reduced model log likelihood ratio = -2600.99.

² Estimated regression coefficients of a mixed-effects, random-coefficient model of weight on time adjusted for age and baseline weight, with no interaction terms.

TABLE 4

Mixed-effects, random-coefficient model of weight change as a function of activity energy expenditure (AEE)¹

	Coefficient	95% CI	P
Model 1: log likelihood ratio = -2601.40 ²			
Baseline weight (kg)	0.990	0.976, 1.004	<0.001
Age (y)	-0.006	-0.027, 0.016	0.73
Time (y)	0.545	0.266, 0.824	<0.001
AEE (MJ/d)	-0.072	-0.287, 0.143	0.51
Site	0.073	-0.523, 0.668	0.81
Model 2: log likelihood ratio = -2599.00 ³			
Baseline weight (kg)	0.990	0.976, 1.004	<0.001
Age (y)	-0.005	-0.027, 0.017	0.65
Time (y)	-0.244	-1.143, 0.655	0.59
AEE (MJ/d)	-0.136	-0.361, 0.090	0.24
Site	0.041	-0.578, 0.661	0.90
Time \times AEE	0.228	-0.017, 0.472	0.07
Time \times site	0.107	-0.464, 0.678	0.71

¹ $n = 148$ Nigerian and 172 US women with a total of 987 weight determinations. Likelihood ratio test statistic for a comparison of model 1 and model 2: 4.73 ($P = 0.09$).

² Estimated regression coefficients of model using random time coefficients and random intercepts and including AEE, age, and site as fixed effects.

³ Estimated regression coefficients of model using random time coefficients and random intercepts and including AEE, age, and site as fixed effects and including interaction terms for time-by-AEE and time-by-site.

ciation between EE and weight change for those participants who completed all annual follow-up examinations compared with those completing <3 . In addition, sensitivity analyses that randomly assigned persons missing any follow-up exam to either high levels of weight gain (ie, 90th percentile) or weight loss (10th percentile) had no effect on the outcome. Likewise, propensity score analysis incorporating baseline information was used to adjust for possible selection bias. Briefly, the probability (propensity) of having ≥ 2 weight determinations versus weight measured at only baseline was estimated by using multivariate logistic regression with age, BMI, and site as covariates. Subsequently, the propensity score was entered as an additional covariate in the multilevel models and yielded results similar to the outcome before adjustment.

DISCUSSION

We showed that 3-y weight change was not associated with baseline levels of adjusted TEE, REE, or AEE in either of 2 cohorts of women living in very different sociocultural environments. Likewise, mean activity levels were similar in the 2 groups despite widely divergent rates of overweight and obesity. On the basis of a small subsample of participants, activity level was observed to be a reasonably stable trait (within-person correlation = 0.8) and likely persisted at similar levels during the follow-up interval. These data therefore suggest that habitual patterns of energy expenditure within the range of variation observed in the general population do not have a large impact on short-term weight change. It remains possible, of course, that more subtle effects went undetected. If this were true, one could nonetheless conclude that AEE plays a very limited role in age-related weight gain.

TABLE 5Activity energy expenditure (AEE) and physical activity level (PAL) by tertile of weight change¹

Tertiles of weight change (kg/y)	Adjusted AEE (MJ/d)		PAL (TEE/REE)	
	Nigeria	United States	Nigeria	United States
<-0.18	3.26 ± 1.28	3.07 ± 0.99	1.73 ± 0.28	1.73 ± 0.20
-0.18 to 1.27	3.36 ± 1.05	2.93 ± 1.27	1.78 ± 0.23	1.69 ± 0.26
>1.27	3.52 ± 1.64	3.30 ± 0.85	1.81 ± 0.35	1.78 ± 0.16

¹ All values are mean ± SD; *n* = 148 Nigerian and 172 US women. TEE, total energy expenditure; REE, resting energy expenditure. All comparisons across tertiles of weight change within site were nonsignificant (ANOVA).

The relative importance of AEE, in contrast with energy intake, in the pathogenesis of obesity has been debated since initiation of this research field. Theoretical analyses have concluded that AEE should be at least as important as energy intake (2, 26, 27). Reviews of the extant data on the relation between self-reported physical activity and weight change have reached inconsistent conclusions (28–30). Wareham et al argued that the majority of studies in which questionnaires were used suggest that only a weak association exists between low levels of activity and future weight gain (28). Earlier reviews advance evidence that relatively high levels of self-reported physical activity (eg, an increment in energy expenditure of 0.9–1.2 MJ/d or an average PAL of 1.8) are likely to prevent weight gain. As noted, however, questionnaire-based EE and physical activity data are poorly correlated with EE, and the association to weight is subject to residual confounding by other aspects of lifestyle (31). In contrast with the studies in which physical activity was self-reported, an inverse correlation between AEE and weight change was not found in prospective analyses based on objective measurement (8, 9).

REE accounts for ≈60% of total EE; however, it is tightly regulated and most interindividual variation is explained by body size and composition. Tataranni et al (8) observed a significant inverse association between REE and weight gain in the cohort of Pima Indians. We found no association between REE and weight change in either of the cohorts we report here. On the other hand, in a separate prior study involving a larger sample of both men and women in Nigeria (*n* = 744), we did observe a small but significant positive association (ie, not negative, as found among the Pima Indians) (32). It is possible that the relation between EE and risk of weight gain varies with the average level of EE or other causal risk conditions, such as dietary patterns. On the other hand, these contradictory findings may reflect only sampling variation.

Major shifts in physical activity patterns accompanying social and economic development, predominantly in occupational and daily living activities have occurred with modernization (2, 33, 34). At the same time, survey data suggest that in recent decades leisure-time activity is increasing in developed countries (35, 36). The contrast between wealthy and poor societies should provide insight into the broad social trends in EE. Somewhat surprisingly, a detailed review of the physical activity data does not support the widely held belief that populations in developing countries expend more energy than do those in developed countries (37). Our data speak directly to the question of temporal trends by demonstrating that there is currently no large gradient in EE between villages in Africa and a middle-class

American community. Needless to say, the specific forms of activity varied between the groups. In particular, the main reason why women in the United States were not in the sedentary range of expenditure was the increased energetic cost of movement. Adjustment for body size, such as PAL, may in fact not fully capture the underlying factor that EE is attempting to measure. PAL should more accurately be termed “physical activity energy expenditure level” because the relation between physical activity, physical AEE, and PAL is confounded by body weight. An individual may reach high levels of PAL in more than one way: eg, they can have a small body size with low energy costs for an activity and spend many minutes in various activities or have a large body with high energy costs for an activity and spend little time in physical activity (38). Because many investigators equate physical activity with time spent being active, the term PAL is often misinterpreted.

Some surveys have documented rural-urban differences in physical activity that are correlated with relative weight. Pima Indians living on a federal reservation in Arizona were shown to have significantly lower AEE, as measured by DLW, and higher body weight than a related population living in rural Mexico (6). A recent study from Tanzania indicated that rural women and men were leaner than their urban counterparts and reported much higher levels of activity by questionnaire (39). The Tanzanian women reported twice the level of EE that we observed in Nigeria, however (7.3 compared with 3.4 MJ/d), suggesting that either the questionnaire data were not comparable with our measurement with DLW or the physical burden of work activities was very different. At the very least, the extant data support the conclusion that elevated AEE is not a prerequisite for avoidance of weight gain. It is important to note, however, that this statement applies to AEE, and AEE is not synonymous with many perceptions of physical activity, particularly in comparisons of groups with different body weights. As documented (40), lean and obese individuals with similar AEE values may have very different time allocations for physical activities; the obese spend more time sitting or lying down than do the lean. Future studies of AEE should also include measures of time allocations of activities to dissect these contrasting aspects of physical activity.

Although the present study was prospective in design, it had limitations. Energy intake was not measured, because it is not technically feasible in free-living individuals. Absence of intake data, of course, does not prevent an unbiased estimation of the independent role of expenditure. Follow-up was near complete among the Nigerian participants (95%) and provides an unbiased estimate of the effect. However, attrition was considerably higher

at the US site (ie, 25%). There were no apparent significant differences in attributes of interest at baseline in completers and noncompleters, with the exception of age in the Nigerians (data not shown). Furthermore, it should be noted that the potential for bias from differential dropout depends on systematic differences in the within-person relation of AEE with weight change. Sensitivity analyses showed that even large differences in the AEE-weight change relation in the noncompleters would not have introduced that bias. It would also have strengthened the study if we had been able to replicate the TEE measurements, both in a larger subsample to provide a more stable estimate of the intraindividual variation in TEE and in the cohort as a whole at the end of the 3-y follow-up to examine the impact of change in AEE (41, 42). Finally, over this time period, the slope of weight change was the same in the 2 populations. If that pattern persisted over a lifetime, the Nigerian population would eventually include many individuals who were obese. Our ongoing surveys of 8000 adults in these same communities rule out this possibility unless we inadvertently detected an extremely rapid temporal shift or a specific age-related phenomenon. Neither of these factors, however, could account for the absence of a within-cohort relation between AEE and weight change.

Controlling the widespread tendency to gain significant amounts of weight with age is clearly a central public health challenge in countries all over the world. Little doubt exists that increased EE, particularly that expended during physical activity, is important for improving physical fitness levels and cardiovascular health (43, 44). In addition, it has been shown that objectively measured AEE, by the DLW technique, is strongly associated with a lower risk of mortality in older adults (45). However, the role of small variations in AEE as part of daily activities in a public health strategy to prevent obesity remains very much in doubt. In defining public policy, it will be crucial to discriminate between the known health benefits of physical activity and the presumed effect on weight change.

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REFERENCES

- James PT. Obesity: the worldwide epidemic. *Clin Dermatol* 2004;22:276–80.
- Popkin BM, Gordon-Larsen P. The nutrition transition: worldwide obesity dynamics and their determinants. *Int J Obes Relat Metab Disord* 2004;28(suppl 3):S2–9.
- Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006;295:1549–55.
- Luke A, Durazo-Arvizu RA, Rotimi CN, et al. Activity energy expenditure and adiposity among black adults in Nigeria and the United States. *Am J Clin Nutr* 2002;75:1045–50.
- Kaufman JS, Durazo-Arvizu RA, Rotimi CN, McGee DL, Cooper RS. Obesity and hypertension prevalence in populations of African origin. The Investigators of the International Collaborative Study on Hypertension in Blacks. *Epidemiology* 1996;7:398–405.
- Esparza J, Fox C, Harper IT, et al. Daily energy expenditure in Mexican and USA Pima Indians: low physical activity as a possible cause of obesity. *Int J Obes Relat Metab Disord* 2000;24:55–9.
- Ebersole K, Dugas L, Durazo-Azivu R, et al. Energy expenditure and adiposity in Nigerian and African American women. *Obesity* 2008;16:2148–54.
- Tataranni PA, Harper IT, Snitker S, et al. Body weight gain in free-living Pima Indians: effect of energy intake vs expenditure. *Int J Obes Relat Metab Disord* 2003;27:1578–83.
- Ekelund U, Brage S, Franks PW, et al. Physical activity energy expenditure predicts changes in body composition in middle-aged healthy whites: effect modification by age. *Am J Clin Nutr* 2005;81:964–9.
- Cooper R, Rotimi C, Ataman S, et al. The prevalence of hypertension in seven populations of west African origin. *Am J Public Health* 1997;87:160–8.
- Cooper RS, Rotimi CN, Kaufman JS, et al. Prevalence of NIDDM among populations of the African diaspora. *Diabetes Care* 1997;20:343–8.
- Schoeller DA, van Santen E. Measurement of energy expenditure in humans by doubly labeled water method. *J Appl Physiol* 1982;53:955–9.
- Schoeller DA, Ravussin E, Schutz Y, Acheson KJ, Baertschi P, Jequier E. Energy expenditure by doubly labeled water: validation in humans and proposed calculation. *Am J Physiol* 1986;250:R823–30.
- Schoeller DA, Taylor PB. Precision of the doubly labelled water method using the two-point calculation. *Hum Nutr Clin Nutr* 1987;41:215–23.
- Phillips P. The metabolic cost of common West African agricultural activities. *J Trop Med* 1954;57:12–20.
- Heini AF, Minghelli G, Diaz E, Prentice AM, Schutz Y. Free-living energy expenditure assessed by two different methods in rural Gambian men. *Eur J Clin Nutr* 1996;50:284–9.
- Ferro-Luzzi A, Scaccini C, Taffese S, Abera B, Demeke T. Seasonal energy deficiency in Ethiopian rural women. *Eur J Clin Nutr* 1990;44(suppl 1):7–18.
- Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* 1949;109:1–9.
- Luke A, Rotimi CN, Adeyemo AA, et al. Comparability of resting energy expenditure in Nigerians and U.S. blacks. *Obes Res* 2000;8:351–9.
- Reed GW, Hill JO. Measuring the thermic effect of food. *Am J Clin Nutr* 1996;63:164–9.
- Schoeller DA, van Santen E, Peterson DW, Dietz W, Jaspan J, Klein PD. Total body water measurement in humans with ^{18}O and ^2H labeled water. *Am J Clin Nutr* 1980;33:2686–93.
- Wang Z, Deurenberg P, Wang W, Pietrobelli A, Baumgartner RN, Heymsfield SB. Hydration of fat-free body mass: new physiological modeling approach. *Am J Physiol* 1999;276:E995–1003.
- Willett W, Stampfer MJ. Total energy intake: implications for epidemiologic analyses. *Am J Epidemiol* 1986;124:17–27.
- Hedeker D, Gibbons RD. Application of random-effects pattern-mixture models for missing data in longitudinal studies. *Psychol Methods* 1997;2:64–78.
- Institute of Medicine. Dietary reference intakes: energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: National Academy Press, 2002. Available from: <http://www.nap.edu/books/0309085373/html> (cited 5 March 2008).
- Prentice A, Jebb S. Energy intake/physical activity interactions in the homeostasis of body weight regulation. *Nutr Rev* 2004;62:98–104.
- Luis Giera J, Maria Manzanarez J, Barbany M, Contreras J, Amigo P, Salas-Salvado J. Physical activity, energy balance and obesity. *Public Health Nutr* 2007;10:1194–9.
- Wareham NJ, van Sluijs EM, Ekelund U. Physical activity and obesity prevention: a review of the current evidence. *Proc Nutr Soc* 2005;64:229–47.
- Erlichman J, Kerbey AL, James WP. Physical activity and its impact on health outcomes. Paper 2: Prevention of unhealthy weight gain and obesity by physical activity: an analysis of the evidence. *Obes Rev* 2002;3:273–87.
- Fogelholm M, Kukkonen-Harjula K. Does physical activity prevent weight gain—a systematic review. *Obes Rev* 2000;1:95–111.
- Neilson HK, Robson PJ, Friedenreich CM, Csizmadia I. Estimating activity energy expenditure: how valid are physical activity questionnaires? *Am J Clin Nutr* 2008;87:279–91.
- Luke A, Durazo-Arvizu R, Cao G, Adeyemo A, Tayo B, Cooper R. Positive association between resting energy expenditure and weight gain in a lean adult population. *Am J Clin Nutr* 2006;83:1076–81.

33. Popkin BM. The nutrition transition and its health implications in lower-income countries. *Public Health Nutr* 1998;1:5–21.
34. Popkin BM. The nutrition transition and obesity in the developing world. *J Nutr* 2001;131:871S–3S.
35. Fox KRL. Living in Britain: results from the sport and leisure module of the 2002 General Household Survey. London, United Kingdom: Office for National Statistics, 2004:3–15.
36. Centers for Disease Control and Prevention. Prevalence of no leisure-time physical activity—35 states and the District of Columbia, 1988–2002. *MMWR Morb Mortal Wkly Rep* 2004;53:82–6.
37. Ferro-Luzzi A, Martino L. Obesity and physical activity. In: Chadwick DJ, Cardew G, eds. *Ciba Foundation Symposium 201: the origins and consequences of obesity*. New York, NY: John Wiley & Sons, 1996:207–27.
38. Levine JA, McCrady SK, Lanningham-Foster LM, Kane PH, Foster RC, Manohar CU. The role of free-living daily walking in human weight gain and obesity. *Diabetes* 2008;57:548–54.
39. Mbalilaki JAHM, Masesa Z, Hostmark AT, Sundquist J, Stromme SB. Physical activity and blood lipids in rural and urban Tanzanians. *Nutr Metab Cardiovasc Dis* 2007;17:344–8.
40. Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. *Science* 2005;307:584–6.
41. Bailey BW, Tucker LA, Peterson TR, LeCheminant JD. A prospective study of physical activity intensity and change in adiposity in middle-aged women. *Am J Health Promot* 2007;21:492–7.
42. Schmitz KH, Jacobs DR Jr, Leon AS, Schreiner PJ, Sternfeld B. Physical activity and body weight: associations over ten years in the CARDIA study. *Int J Obes Relat Metab Disord* 2000;24:1475–87.
43. Wei M, Kampert JB, Barlow CE, et al. Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *JAMA* 1999;282:1547–53.
44. Talbot LAME, Fleg JL. Leisure-time physical activities and their relationship to cardiorespiratory fitness in healthy men and women 18–95 years old. *Med Sci Sports Exerc* 2000;32:417–25.
45. Manini TM, Everhart JE, Patel KV, et al. Daily activity energy expenditure and mortality among older adults. *JAMA* 2006;296:171–9.